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PORTABLE COUNTING INTEGRATOR FOR LOW-VOLTAGE SIGNALS

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PORTABLE COUNTING INTEGRATOR FOR LOW-VOLTAGE SIGNALS

R. J. Hanks² and H. R. Gardner¹

This report describes an integrator for low-voltage signals that is inexpensive, fairly reliable, and portable. The integrator previously described by the authors² has not been completely satisfactory because of frequent coulometer "blow-out"; consequently, the coulometer was replaced with a counting system.

The integrator has been used with low-voltage signals from net radiometers, soil heat flow plates, and pyrhemeters. The integrator should function with any transducer that has a low impedance.

The schematic diagram of the integrator is shown in figure 1. The output current of the amplifier, I_{out} , is related to the input voltage, E_{in} , by $I_{out} = E_{in}/R_f$, where R_f is the gain control (feedback) resistance. I_{out} is independent of the voltage across the capacitor, C_1 , as long as the voltage across the capacitor, V_c , is less than about 11 volts. The output current charges up capacitor C_1 until the voltage across the silicon control switch, SCS, reaches the switching voltage. At the switching voltage, the SCS "closes," causing the capacitor to discharge through the counting relay, and one count is registered. Upon discharging, the capacitance-inductance (relay coil) circuit starts to oscillate, which "opens" the SCS as soon as the voltage across the SCS goes negative. At this point, the capacitor starts to charge up again. Thus, the number of counts registered over a period of time will be proportional to the time integral of I_{out} (or E_{in}).

The switching voltage, V_c , of the SCS is determined by the voltage at the cathode gate. With the arrangement shown in figure 1, V_c can be adjusted from about 8 to 10 volts by adjusting R_1 . The thermistor is used to compensate for changes in V_c caused by temperature changes.

To use with a transducer that gives both negative and positive output (such as net radiometers), R_2 is adjusted to give a positive current flow (measured across test terminals) with the input terminals shorted. This reading should be greater than the absolute magnitude of any possible negative output from the transducer.

With a signal connected to the input terminals (E_{in}), and the impulse relay switch in the position shown in figure 1, counts will accumulate in counter 1 in proportion to $I_o^* = I_o + E_{in}/R_f$ where I_o is zero current, and I_o^* is the amplifier output current. The circuit with the unijunction transistor is a relaxation oscillator that will cause the impulse relay to switch every minute or so. When the impulse relay switches, the EMF leads are reversed with respect to the amplifier terminals. The amplifier output, I_o^* , is then composed of a positive current due to zero offset, I_o , minus the current that is proportional to the EMF signal. Thus, $I_o^* = I_o - \frac{E_{in}}{R_f}$. Therefore, counter 2 will count fewer counts (if E_{in} is positive) than counter 1. Over a period of time the difference between the cumulated counts of counters 1 and 2 will be directly proportional to the input signal with the zero offset current effect being subtracted out. Thus,

$$\int_{t_1}^{t_2} S dt = \frac{C_e V_c R_f}{60K} (\Delta C_1 - \Delta C_2)$$

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²Hanks, R. J. and Gardner, H. R. Portable integrator for net radiation, total radiation, and soil heat flow. Soil Sci. Soc. of Amer. Proc. 28: 449-450, 1964.

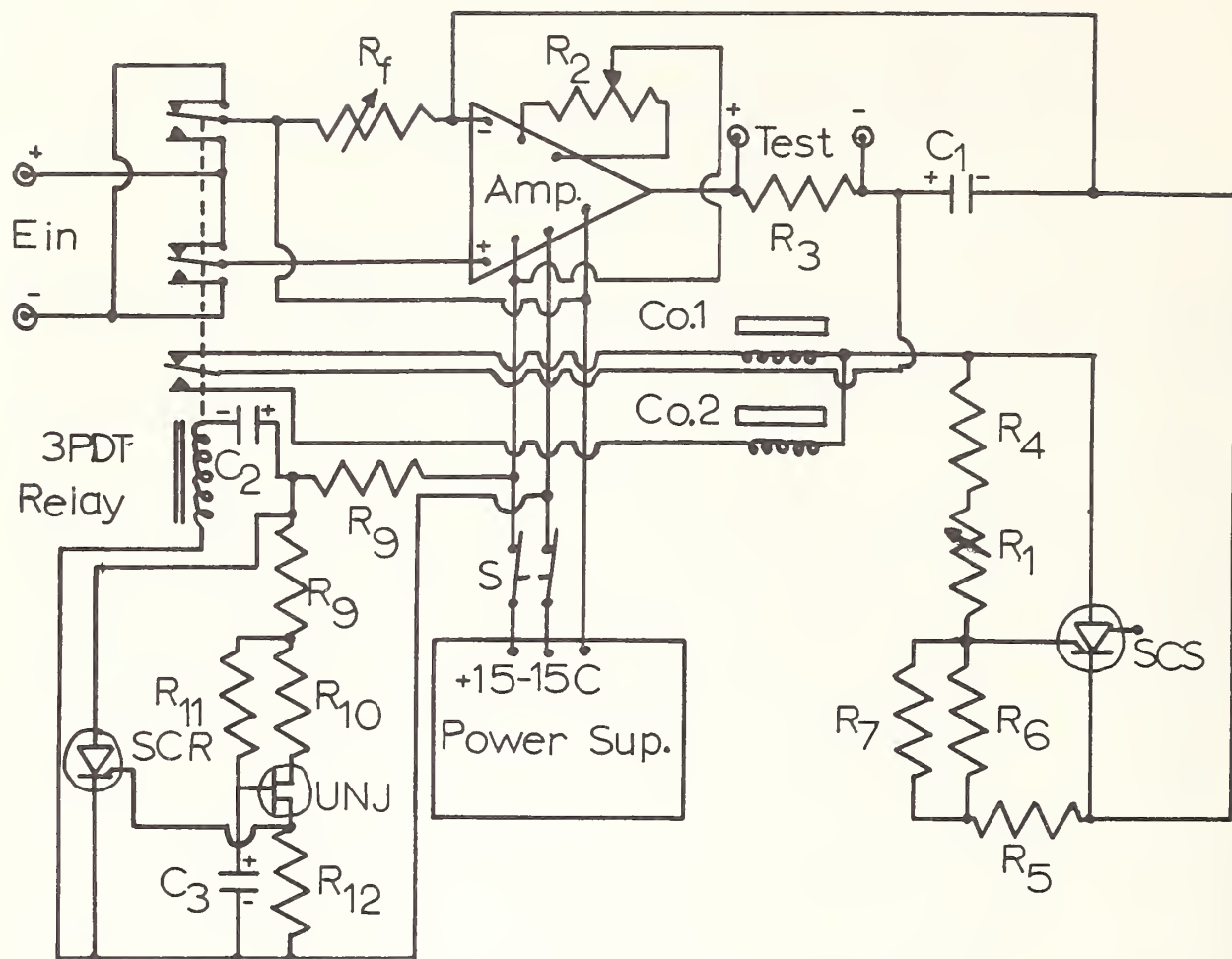


Figure 1.—Schematic diagram of portable counting integrator

Where C_e is the effective capacitance of capacitor C_1 in farads, ΔC_1 is the difference in counts from one time to the next for counter 1, ΔC_2 is the difference in counts from one time to the next on counter 2, K is the transducer constant in volts cal. $^{-1}$ cm. 2 , S is the value to be integrated (cal./cm. 2), and t is time in minutes. If the cumulative counts of counters 1 and 2 are added, the effect of the input signal is subtracted out, and one has a means of evaluating the average value of $\frac{C_e V_c}{60}$ (if I_0 is known) as

$$\frac{C_e V_c}{60} = \frac{I_0 (t_2 - t_1)}{\Delta C_1 + \Delta C_2}$$

To determine the value of $C_e V_c / 60$, the unit should be placed in an environment where the temperature does not change by more than a few degrees because I_0 is dependent on temperature. Once $C_e V_c / 60$ is determined, the unit can be placed in the field where the temperature is not controlled. The zero current will respond to temperature but this will not influence the readings, since the variation is slow and is essentially equal when counting on counter 1 or 2.

The main source of error is caused by variations of properties of the electrolytic capacitor. The leakage of the capacitor as well as the absolute capacitance may change both with time and temperature. Frequent checks of C_e should be made to minimize this error. However, preliminary tests indicate this error to be well within the 5-percent design error desired.

Another error inherent in this method--that due to the finite time required for a given count--can be minimized by allowing relatively large time intervals between readings. The percentage error is inversely proportional to the number of counts between two readings and is given by percent error = $\frac{100}{\Delta C_1 - \Delta C_2}$. Thus, if the difference in counts $\Delta C_1 - \Delta C_2$ is greater than 100, the error here would be less than 1 percent; large errors would result if readings are taken at short time intervals so that $\Delta C_1 - \Delta C_2$ is small.

To test the unit, the input terminals (EMF) should be shorted out and the voltage measured across the test terminals. By adjusting R_2 , I_0 can be adjusted to the desired value (evaluated by measuring the voltage drop across R_3 , since $V = I_0 R_3$). With a voltmeter a low internal resistance will cause part of I_0 to flow through the voltmeter and a reading will be too low. This can be corrected by calculating the parallel resistance of the voltmeter and R_3 or by using a voltmeter with a high internal resistance. The authors use a volt-ohm-millammeter of 20,000 ohms/volt rating, so on the 1-volt scale they have about 5 percent error if the effect of voltmeter resistance is ignored. An alternative method would be to use the millivolt scale on the VOM and multiply the reading by an appropriate correction factor.

To determine if the voltage is building up across C_1 , the voltmeter should be set on the 10-volt scale and measured between ground and test minus. This is essentially measuring the voltage across C_1 .

An example might be in order. With inputs shorted, $C_e V_c / 60$ was computed for an integrator from the following data: $t_2 - t_1 = 1,440$ minutes, $\Delta C_1 = 2,025$, $\Delta C_2 = 2,020$, and $I_0 = 0.5$ mv. Thus, $C_e V_c / 60 = \frac{0.5 \times 10^{-3} \times 1,440}{2,025 + 2,020} = 0.179 \times 10^{-3}$. This integrator was then used with a net radiometer with a constant $K = 3.0$ mv. cal.⁻¹ cm.²; with $R_f = 10$ ohms, the counts obtained after a period of one day were $\Delta C_1 = 2,810$ and $\Delta C_2 = 2,250$. Thus,

$$\int_{t_1}^{t_2} S dt = \frac{0.179 \times 10^{-3} \times 10}{3.0 \times 10^{-3}} \times (2,810 - 2,250) = 334 \text{ cal. cm.}^{-2}.$$

A list of materials is given in the following table. Very few of the items are critical and other brands could be substituted except for the SCS. In some units a precision 10-ohm resistor for R_f has been used, since a variable resistor is not needed there. However, it may be convenient to set R_f equal to $60K / C_e V_c$ to eliminate the need for a conversion factor.

LIST OF MATERIALS¹

<u>Item</u>	<u>Supplier</u> ²	<u>Cost</u>
Operational amplifier, Model SA-2	Nexus Research Lab. Inc. 480 Neponset Street Canton, Mass. 02021	\$27.00
R_f - 10-turn, 25-ohm potentiometer with dial, 1 RC Type 8000	*	15.75
R_1 - 200 K potentiometer 10% Clarostat Type 53C1	*	1.75
R_2 - 100 K ohm potentiometer 10% Clarostat Type 53C1	*	1.75

See footnotes on page 5.

LIST OF MATERIALS¹(Continued)

<u>Item</u>	<u>Supplier²</u>	<u>Cost</u>
R ₃ - 1000 ohm precision resistor 1% RC Type DCC	*	\$0.54
R ₄ - 820 K 5% 1/4 watt Ohmite	*	.26
R ₅ - 20 K 5% 1/4 watt	*	.26
R ₆ - 47 K 5% 1/4 watt	*	.26
R ₇ - 100 K ohm (25 ⁰) thermistor Fenwall QA51J1	*	1.25
R ₉ - 10,000 ohm 5% 1/4 watt (2 needed @ .26)	*	.52
R ₁₀ - 600 ohm 5% 1/4 watt	*	.26
R ₁₁ - 200 K 5% 1/4 watt	*	.26
R ₁₂ - 50 ohm 5% 1/4 watt	*	.26
C ₁ - 550 ohm electrolytic capacitor, 350 V Mallory #CG551T350D1	*	3.87
SCS Silicon control switch GE 3N81 or 3N58	*	3.40
Terminals (4 needed at 60 cents) H. H. Smith #209	*	2.40
Power switch, DPDT, CH #8360K8	*	.95
Chassis - surplus instrument case	--	--
C ₂ 1500-2000 mfd. capacitor Mallory #CG152V75C1	*	2.19
C ₃ 100 mfd capacitor C-D #100-150	*	1.05
UNJ 2N2160 Unijunction transistor GE	*	1.49
SCR 20F Silicon control rectifier GE	*	2.63
Counting relay, Sodeco #TCe-5E (2 required @ \$20 each)	Landis & Gyr, Inc. 43 West 45th Str. New York, N.Y. 11377	40.00
3 PDT Impulse relay AZ 170-33-3C	American Zettler, Inc. 687 Randolph Ave. Costa Mesa, Calif. 92626	5.65

See footnotes on page 5.

LIST OF MATERIALS¹(Continued)

<u>Item</u>	<u>Supplier²</u>	<u>Cost</u>
<u>If 110-V AC is available -</u>		
Power Supply #RA-721	Olsen Electronics -	\$33.00
(2 required \pm 15 volts will	260 S. Forge St.	
power several integrators)	Akron, Ohio 44308	
For a portable power supply we use	GSA	1.00
20 size D flashlight batteries (@.05 each),		
which last about 2 weeks		
Total		87.01

¹*Available from most electronic supply houses such as Allied Radio, Chicago, Ill.

²The suppliers' names and prices are listed as a matter of convenience to the reader and such inclusion does not constitute a guarantee or warranty by the United States Department of Agriculture of products named or an endorsement by the Department over other products available on the market.

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